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THE NATURE OF RADIOACTIVE CONTAMINATION AND METHODS OF PROTECTION AGAINST IT

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THE NATURE OF RADIOACTIVE CONTAMINATION AND METHODS OF PROTECTION AGAINST IT

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I

RADIOACTIVE CONTAMINATION

Formation of Radioactive Substances as a Result of Nuclear Explosions

Injurious elements produced by the explosion of a nuclear weapon such as the shock wave, luminous radiation and penetrating radiation, are accompanied by radioactive contamination.

The nature and peculiarities of radioactive contamination will be examined in detail later, at this point, let us direct our attention to just two of the most important features which determine the role and place of radioactive contamination among the other injurious elements of a nuclear detonation.

First of all the bulk of the energy released by a nuclear blast, determining the strength of the shock wave, luminous radiation and penetrating radiation, is generated at the moment of the explosion and in the next 10-15 seconds, in connection with which the most intensive damage effect is produced within limited periods of time. At the same time the radioactive contamination produced by the explosion is preserved for a long time and its injurious action may be observed for many hours, days or for even longer periods of time.

Second, radioactive contamination threatens humans and animals in a very large area. The area that is radioactively contaminated exceeds the area in which injuries occur as a result of other elements of the nuclear blast.

Thus the radioactive contamination occurring after a nuclear blast deserves special attention and must be considered as one of the injurious elements.

The formation of radioactive substances following nuclear explosions occurs as a result of three main processes. The principal mass of radioactive substances is formed during the chain reaction occurring when the nuclear charge is detonated. The nuclear charge is either Plutonium-239 or Uranium-235 and Uranium-233. During the explosion there occurs a nuclear fission of the uranium of plutonium atoms splitting them into two parts (fragments). Fission may occur in different ways, therefore initially there is formed about 60 isotopes of 34 different chemical elements with an atomic weight of from 70 to 160. The most widespread isotopes among the fission fragments are

yttrium, tellurium, molybdenum, iodine, zenon, barium, lanthanum, zirconium and other isotopes. The bulk of the fission fragments that form are unstable and undergo an average of three radioactive disintegrations. Therefore the total amount of radioactive fragments in the fission products increases with time to 200.

In addition to this the overall mass of radioactive isotopes formed by the nuclear explosion is supplemented by a certain amount of radioactive substances accounted for by the part of the charge that did not participate in the chain reaction of the explosion.

The thing is that the nuclear charge utilization factor is rather low and, in the opinion of foreign specialists, depending on the design and other peculiarities of the bomb, may fluctuate within limits of up to 10%. This means that the nuclei of the main mass of the charge (Plutonium-239 or Uranium isotopes) do not have time to undergo fission and are scattered by the force of the explosion into the tiniest particles which bear the radioactive properties of the initial isotopes of Uranium or Plutonium.

The third process accompanying the nuclear explosion, as a result of which radioactive substances are formed, is the process involving the exertion of an influence on the atoms of various substances in the environment surrounding the neutron flux. In this reaction the atomic nuclei of many chemical elements are captured by neutrons, as a result of which radioactive isotopes appear in materials out of which the body or other parts of the bomb are made, as well as in the air, in the soil and in the buildings. These isotopes (natural or induced radioactivity) consist of such elements as iron, manganese, aluminum, sodium, silicon, calcium, carbon and others.

The formation of radioactive substances during the explosion of thermonuclear weapons has certain peculiarities. As commonly known the functioning of the hydrogen bomb is based on the coupling of hydrogen isotopes (deutrium and tritium) into an atom of the chemical element helium. Nuclear reaction occurs only at a very high temperature measured in several million degrees. Therefore in order to heat the reaction mixture of hydrogen isotopes the energy released by the detonation of an ordinary atomic bomb is used. The atomic bomb is made with Plutonium or Uranium isotopes. In this case the atomic bomb plays the role of a "fuse" for a hydrogen charge.

With the detonation of a nuclear bomb there occurs a very powerful neutron flux under whose effect there forms a large amount of artificial radioactive isotopes in the materials and mediums through which it passes. Since the neutron flux is much more powerful than the neutron flux produced by an ordinary atomic explosion, there will be a corresponding increase in the artificial radioactive isotopes formed by the explosion of a nuclear bomb.

In addition to that the amount of radioactive substances increases considerably if Uranium-238 has been added to the hydrogen charge of the bomb. This Uranium isotope, the most widespread in nature, by contrast with Uranium-235 and Uranium-233, is not used in atomic bombs, since it is incapable of nuclear fission under the conditions necessary to detonate the atomic bomb with a charge of

Uranium-235 or Uranium-233. With the explosion of the hydrogen part of the charge of such a bomb, however, Uranium-238, which is subjected to the bombardment by a very powerful neutron flux, occurring in a thermonuclear reaction, undergoes a series of transformations, begins to split and "explodes." As a result there is a significant increase in the energy released by the explosion and in the amount of radioactive substances that are formed.

Before moving on to a detailed description of the characteristics of radioactive contamination accompanying nuclear explosions, and to evaluation of its possible scales and degree of danger it presents to the rural and urban population, we should examine the basic properties of radioactive substances and the destructive action of the radiation they emit.

Fundamental Properties of Radioactive Substances

Radioactive substances are substances whose atomic nuclei have the capacity of spontaneously changing into atomic nuclei of other chemical elements while at the same time emitting invisible radioactive ionizing radiation. The processes of the internal reconstruction of the atomic nuclei of certain elements are called radioactive decay and are the consequence of the spontaneous shift of these nuclei from a less stable to a more stable energy state.

Under natural conditions radioactive properties are most characteristic of the heavy elements. At the present time over forty naturally radioactive elements are known. In addition to that radioactive substances may be produced artificially by bombarding the nuclei of stable elements with neutrons, protons and other particles.

More than a thousand different artificial radioactive isotopes are today produced in the nuclear reactors and accelerators. Many of these isotopes are used on quite a large scale in various fields of science, technology, medicine and agriculture.

Artificial radioactive substances, as already pointed out above, are produced in large amounts following nuclear explosions. Alpha and beta particles are emitted at high speed from the atomic nuclei in the process of radioactive decay. All the nuclei of a given radioactive isotope, as a rule, emit particles of the same kind.

In many cases the atomic nuclei of new elements, that form as a result of radioactive decay, prove to be excited, and in shifting to a non-excited state, emit gamma-quanta. Gamma radiation is emitted also in special types of radioactive transformation without the escape of alpha and beta particles from the atomic nuclei -- in the so-called K-capture, and isomeric transition.

One of the examples of alpha-disintegration is the disintegration of element Radium-226, which, when undergoing nuclear changes, emits an alpha-particle and changes into element Radon-222 (Fig. 1a). An example of beta-disintegration is the disintegration of the radioactive isotope -- Sodium-24. As a result of the escape of the beta-particle from the sodium nucleus there forms the isotope -- Magnesium-24

and the emission of two gamma-quanta occurs (Fig. 1b).

During radioactive decay the chemical elements are transformed into stable isotopes, but very frequently these transformations comprise an entire series of consecutive changes, in the process of which intermediary radioactive isotopes are formed.

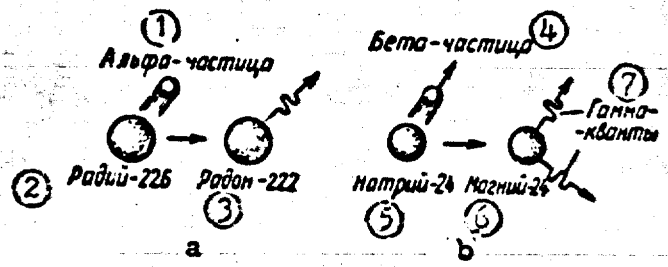


Fig. 1. Diagram showing radioactive decay.

Legend: 1 -- Alpha-particle; 2 -- Radium-226; 3 -- Radon-222; 4 -- Beta-particle; 5 -- Sodium-24; 6 -- Magnesium-24; 7 -- Gamma-quanta.

Alpha and beta-particles, as well as gamma-quanta, which are emitted by the nuclei of the elements during radioactive transformations, represent radioactive radiation comprising the basis of the damaging action of the radioactive substances.

As a result of the fact that alpha and beta-particles as well as gamma-quanta are usually emitted by a mixture of isotopes or radioactive elements in the form of a continuous stream, it is frequently called, alpha, beta, and gamma radiation.

In their physical nature alpha-radiation represents a stream of helium nuclei, having two units of positive charge and an atomic weight of 4. Alpha-particles escape from the nuclei of radioactive isotopes at speeds of as high as 20,000-25,000 kilometers per second. The energy of these particles, emitted by the isotopes known at the present time, fluctuates within the limits of 3-9 Mev (million electron volts) [See Note].

([Note]. Electron volt (ev) is a unit of energy used in nuclear physics. It is equal to the energy acquired by an electron that passes through a potential difference of one volt (v). 1 Mev = 10^6 ev.)

Beta radiation represents streams of electrons or positrons [See Note], that are emitted by nuclei of radioactive isotopes and travel at a speed of up to 270,000 kilometers per second. The maximum energy of these particles for different isotopes varies from several tens of thousands of electron volts to 3-3.5 Mev.

([Note]. Positron -- a particle having the same mass as an electron, but with a positive charge.)

Gamma radiation, just as visible light, ultraviolet and

infrared rays, radio waves and X-rays, consists of a stream of electromagnetic oscillations propagated in a vacuum at a constant speed equal to 300,000 kilometers per second. Having the same nature, gamma radiation is distinguished only by its shorter wave length and greater energy. The energy of gamma radiation, emitted in the process of radioactive decay, fluctuates approximately within the same limits as the energy of beta radiation.

Because of the short nature of this brochure it is impossible to give a more detailed description of all the peculiarities of the phenomena known as radioactivity. Therefore we shall first give a brief description of the fundamental properties of radioactive substances and nuclear radiation, which directly determine the nature of their damaging effect. This will make it easier to understand the methods of protection against radioactive radiation. With this in mind it is most useful to direct attention at the length of time radioactive substances last, the intensity of radiation emitted by them, the penetrating capability of reduction, interaction with different substances and materials, and, finally, the harmful effect of radiation on humans and animals.

The radioactive decay of any of the natural or artificial radioactive elements occurs at a definite rate strictly characteristic of such an element. This occurs because in the process of radioactive decay not all the nuclei of a given radioactive element disintegrate simultaneously and, regardless of the initial amount of the radioactive isotope, only a certain part of all the available atomic nuclei disintegrate during each unit of time. Therefore with time the amount of initial radioactive atoms gradually decreases. The time during which the amount of radioactive atoms decreases by two times is commonly referred to as half-decay.

Let us assume that we have a radioactive isotope Sodium-24 with a half-life of 15 hours in an amount of 100 grams and 10 grams. In 15 hours only half of the radioactive isotope will remain, in both cases, i.e. 50 grams and 5 grams. In another 15 hours only 25 grams and 2.5 grams of the Sodium-24 isotope will remain. Thus with time less and less of the radioactive isotope will remain.

Various radioactive isotopes have very different half-life periods fluctuating between millionths of a second to billions of years:

Barium-141..............	18 minutes
Iron-59.................	45 days
Yttrium-90..............	61 hours
Cobalt-60...............	5.3 years
Sodium-24...............	15 hours
Plutonium-90............	$2.4 \cdot 10^{4}$ years
Polonium-212............	$3 \cdot 10^{-7}$ seconds
Strontium-90............	27.7 years
Uranium-235.............	$707 \cdot 10^{6}$ years
Uranium-238.............	$4.5 \cdot 10^{9}$ years
Cesium-137..............	33 years

One of the important characteristics of every radioactive isotope is its activity which indicates the number of atoms decaying during each unit of time. The activity is a measure of the amount of radioactive substances. The curie is considered as a unit of activity. The activity of a radioactive substance is equal to one curie. There are $3.7 \cdot 10^{10}$ disintegrations per second of any radioactive nuclide.

The ability of radioactive radiation to penetrate various substances and at the same time cause the ionization of atoms and molecules of the medium by transmitting its energy to them is a factor of practical significance.

The maximum thickness of a layer of some substance through which alpha, beta and gamma rays can penetrate (path length) as well as the nature of ionization caused by these rays depend on the type of radioactive radiation and its energy.

The process of ionization caused by radioactive radiation involves the formation of pairs of contaminated particles among the molecules and atoms of the substance: on the one hand positive ions or atoms which have lost one or several electrons, and on the other hand free electrons or atoms that have gained an electron thereby acquiring a negative charge.

Radioactive radiation in passing through some substance gradually lose their energy as a result of interaction with electrons and nuclei of the substance. Therefore the greater the ioninizing capability of the radiation, the more rapidly it loses its energy and the less its penetrating capacity.

Alpha radiation has the greatest ionizing capability. At the same time, as seen in Table 1, the path length of alpha-particles in various mediums is comparatively limited.

Table 1

Path Length of Alpha Particles in Certain Substances

Isotope	Half-life	Energy of alpha-particles, Mev	Path length, cm in the air	Path length, cm in soft biological tissue
Uranium-238	$4.5 \cdot 10^9$ years	4.2	2.7	0.034
Plutonium-239	$1.4 \cdot 10^4$ years	5.15	3.7	0.043
Radon-222	3.8 days	5.5	4.0	0.049
Polonium-212	$3 \cdot 10^{-7}$ seconds	8.8	8.6	0.105

Alpha-particles travel only a few centimeters through the air and can affect only the skin surface of humans not protected by clothing. Beta rays have a much smaller ionizing power and are absorbed

by a substance to a much lesser degree (Table 2).

Table 2

Path Length of Beta-Particles in Certain Substances

Isotope	Half-life	Energy of beta-particles, Mev	Minimum path length, cm In the air	In soft biological tissues	In aluminum
Strontium-89	50.5 days	1.50	510	0.70	0.24
Sodium-24	15 hours	1.39	465	0.64	0.22
Cobalt-60	5.3 years	0.31	62	0.09	0.03
Calcium-45	152 days	0.26	46.5	0.06	0.02

The data in Table 2 indicate that the penetrating capacity of beta-particles increases with an increase in their energy. Beta radiation may partly pass through a person's clothing and, penetrating into the body by several centimeters, cause injury. Gamma radiation has the least ionizing power but it has the greatest penetrating capacity.

The Damaging Action of Radioactive Radiation

A harmful effect may be exerted on the unprotected human or animal organism by any type of radiation providing the doses are high enough. In practice, however, primary attention must be directed at gamma-radiation. Despite the fact that the ionizing power of this type of radiation is significantly lower than the power of alpha and beta radiation, it may damage the tissues of vital organs by penetrating deep inside the organism.

As radioactive radiation passes through the cells of living tissue the overall nature of the ionization process differs little from the process of ionization of atoms and molecules of substances and materials of an inanimate nature. The damaging effect and harmful biological action caused by radioactive radiation is determined by the fact that ionization occurs in a medium consisting of complex chamical substances and is accompanied by various undesirable processes involving chemical transformations in the living organism.

It is possible to visualize the following simplified sketch reflecting the occurrence of damaging action as a result of nuclear radiation. The positive and negative ions and atoms of the environmental substance that occur during ionization, exist for only a very limited period of time, measured in millionths of a second. These ions, colliding, join together and form electrically neutral atoms or molecules.

In simple substances, whose molecules consist of atoms of a single element, the coupling of the ions leads to the formation of molecules of the initial substance. In complex substances, whose ions contain atoms of different elements, new active complexes and molecules may occur as the ions couple, causing the development of chemical reactions with the formation of many compounds, new in their compositions and properties. In biological substances the change in chemical properties leads to a disturbance of cell and tissue vitality, and if the radiation is strong, the entire organism will be affected, resulting in radiation sickness.

In evaluating the danger of radioactive radiation it is necessary to take into account that their damaging action may result both from the external irradiation of humans and animals, and from the penetration of radioactive substances inside the organism.

A person is exposed to external irradiation if the source of radiation is outside his organism. If the person is, for example, on contaminated ground, among contaminated objects or if his clothing was irradiated. In this case the harmful action of radioactive radiation lasts only as long as the person remains on contaminated ground or near contaminated objects.

When radioactive substances penetrate inside the organism through digestive or respiratory organs, or through injured skin surfaces, a person is subjected to continuous internal irradiation for a prolonged period of time until the radioactive isotopes change into stable isotopes as a result of natural decay, or until they are expelled from the organism in the metabolic process.

Knowing penetrating and ionizing properties of alpha, beta and gamma radiation, it is possible to conclude that gamma radiation presents greater danger in the case of external irradiation, while with the penetration of radioactive substances inside the organism the greatest danger is presented by alpha and beta radiation.

The degree of the damaging action of various types of radioactive radiation on humans depends on the quantitative changes in the organism, caused by ionization, which, in turn, are determined by the amount of radiation energy absorbed.

In order to make a quantitive evaluation of the absorbed energy of any type of radiation a special unit is used -- rad. A rad is equivalent to 100 ergs of absorbed energy per gram of absorbing material. In order to measure the strength of the absorbed dose units such as rad/second, rad/hour, rad/week, etc., are used.

The size of the absorbed dose of radiation depends on the intensity of radiation, i.e. on the amount of energy transmitted by the radiation through one square centimeter of the surface being irradiated per second, on the duration of irradiation, density of the substance, its chemical nature and on other factors.

In connection with the fact that the direct determination of the absorbed dose in many cases is rather difficult, another unit is used in practice -- roentgen (r).

A roentgen is determined as a dose of roentgen or gamma radiation as a result of which $2.08 \cdot 10^9$ pairs of ions are formed in one

cubic centimeter of air (at 0°C and a pressure of 760 mm of mercury). In other words the roentgen is a unit determining the ionizing power of roentgen and gamma radiation in the air. The dose of roentgen or gamma radiation measured in roentgens, is a measure of radiation based on its ionizing power.

Without examining the relatively complex questions concerning the relationship of the absorbed dose and the radiation dose under different conditions and for different types of radiation in greater detail, it should be noted that within the range of the energies of radioactive radiation accompanying a nuclear explosion, as well as with the observance of corresponding conditions governing the measurement of the dose of radiation in the air in roentgens, it is possible to judge the irradiation dose received by humans on the basis of the dose of radiation in the air.

Let us agree that in the further description of all questions associated with control over the irradiation of humans and with the estimate of the degree of danger presented by such radiation, we will express the dose of radiation in roentgens, while the strength of the doses (radiation levels) will be expressed in roentgens per unit of time; roentgens/hour, milliroentgen/hour, microroentgen/second, etc.

The result produced by the exposure of an unprotected organism to various doses of radiation depend on the person's health, the nature of irradiation, the duration of continuous exposure, as well as on the repetition of such exposures. A dose that may be fatal in case of whole-body irradiation, may not be harmful in the case of local irradiation. The time during which a person is receiving a certain dose of irradiation is very significant. A 600 roentgen dose, for instance, received by the organism for an hour or a day will be fatal, but the same dose received over a 50 year period is practically harmless. Irradiation doses from 25 to 75 roentgens do not injure the organism.

The human organism has the capacity of restoring the disturbed activity of injured tissue, therefore all changes in the composition of the blood and other consequences caused by a single irradiation, even in a comparatively large dose (50 roentgens), will disappear with time.

A single dose of irradiation amounting to 100-250 roentgens may cause a light form of radiation sickness in humans -- first degree radiation sickness. A 250-400 roentgen dose causes second degree radiation sickness, while a dose of over 400 roentgens leads to severe radiation sickness -- third degree radiation sickness [See Note].

([Note]. See also Rekomendatsii NKRZ SShA (Recommendations of the US NCRP), Publishing House of the Main Directorate for Atomic Energy Utilization at the Council of Ministers USSR, 1963.)

The damaging action of radioactive substances located inside the organism is determined, as in the case of external irradiation, by the dose created by these substances during their presence in the organism. Many radioactive isotopes penetrating inside the organism are capable of accumulating in various organs and tissues. Strontium, phosphorus and radium isotopes, for instance, accumulate primarily in

the bones, the cesium isotopes concentrate in muscle tissue, while iodine isotopes accumulate in the thyroid gland. As a result of such accumulation, particularly in the case of alpha and beta active isotopes, there is observed a strong local action of radioactive radiation. In many cases the degree of injury will depend not so much on the size of the dose created by the radiation that is being emitted, as on the organ which was injured and on how the infliction of the given organ affects the vitality of the entire organism.

The methods of detecting and measuring radioactive radiation are based on different physico-chemical processes accompanying the interaction of the radiation with the material comprising the environment. The most widespread method is the ionization method of recording, based on the measurement of the direct effect produced by the interaction of the radiation with the material, i.e. determination of the degree of ionization of atoms and molecules of the material comprising the environment through which radiation passed. Other existing methods are based on the detection and determination of the secondary effects brought about by ionization: film blackening, luminescence of certain objects under the effect of radiation, change in physical and chemical properties of matter. These methods are called photographic, luminescent and chemical methods.

Most of the dosimetric instruments in current use are based on the ionization method of detecting and measuring radioactive radiation (radioactivity indicators, radiometers, roentgen meters and dosimeters).

The presence of radioactive substances on the terrain or in the air, i.e. radioactive contamination is detected with the aid of radioactivity indicators. Roentgenmeters permit the determination of the level radiation or the strength of radiation doses, indicating the nature and density of radioactive contamination of the terrain.

Radiometers serve to determine the degree of danger presented by radioactive contamination of individual objects, parts of the body, clothing, air, water, food, etc.

Dosimeters are used for the individual control of human irradiation by measuring the cumulative dose of radiation received during the stay on contaminated terrain.

Nature and Scales of Radioactive Contamination

In order to understand the nature and possible scales of radioactive contamination following nuclear explosion, and also in order to evaluate the degree of danger presented by such contamination for people, it is necessary to study the peculiarities and conditions involved in the formation of contamination in the area around the explosion of a nuclear device and also along the path of the radioactive cloud.

The nature and scales of radioactive contamination are determined not only by the power of the nuclear bomb, but also by an entire series of other factors. First of all the overall picture of radicactive contamination depends on where the explosion occurred: in the air, on the ground or under the ground (underwater), or, as

they say, on the type of nuclear explosion: air, ground or underground (underwater) explosion.

It is known that when a nuclear bomb explodes a vast amount of energy is released almost instantaneously. As a result of this the temperature in the zone of the nuclear reaction rises to several million degrees. All matter within this zone is transformed into a gaseous state and, together with the adjoining layers of atmospheric air form an incandescent, brilliantly lit ball which, increasing in volume and rising to the upper layers of the atmosphere, gradually cools.

Matter that evaporated in the initial stage of the explosion is condensed in the process of cooling and, in the form of small solid particles (primarily metal oxides), mixed with drops of water that form, comprise the large cloud accompanying nuclear explosions. This cloud contains a large amount of radioactive isotopes. Depending on the power and conditions of the nuclear explosion, this cloud rises to an altitude of 12-20 kilometers and higher in a period of 8-10 minutes.

The rapidly heated products of the nuclear explosion, in rising, form a very powerful updraft which creates a large pillar of dust lifted from the surface of the ground by the shock wave. If the nuclear explosion occurred high up in the air, the dust and ground matter lifted from the surface of the ground do not come in contact with the main products of the explosion. Later that dust settles in the area of the explosion, while the products of fission remain for a long time in the radioactive cloud produced by the explosion, are scattered by the wind, and, gradually losing their activity, settle on the surface of the ground.

As a result in the case of an air explosion the dispersion of radioactive products of the explosion over a very large area of radioactive contamination does not occur. Only in certain cases, under the influence of local terrain peculiarities, wind currents or the intermixture of radioactive products with rain clouds, there occurs an increased contamination in a certain region as a result of heavy fallout of the products of the nuclear explosion.

Radioactive contamination in the area nearest to the zero point of an air explosion is usually insignificant. This is explained by the fact that very little fallout occurs in that area and contamination is determined only by the presence of artificial radioactive isotopes that form on the ground or in other materials as a result of bombardment by a neutron flux.

A completely different picture of radioactive contamination is observed following a ground explosion. In case a large amount of dust raised from the ground as well as chunks of ground tossed out of the crater formed by the explosion, mixes together with radioactive fission products. As a result of this not only the external appearance of the radioactive cloud is different but also the nature of the particles comprising it.

Soon after the explosion the cloud takes the shape of a giant mushroom the upper part of which is comprised of the fireball of incandescent products enveloped in fog, while the "stem" is formed by the dust, earth and other matter lifted from the earth. After a certain

period of time the lower part of the column of dust, consisting primarily of large particles, settles back on the ground near ground zero, while the upper part comes in contact and intermixes with the main part of the radioactive cloud which, as a result of this, has a darker color than the cloud formed by an air explosion.

The cloud produced by a ground explosion will contain a very large amount of suspended solid particles, after it mixes with the dust. These particles are essentially pieces of the ground carrying on their surface smaller particles of oxides of radioactive isotopes. The dimensions of the radioactive dust (individual particles) usually fluctuate between several thousands to tens of a millimeter. Therefore in size and weight these particles are significantly greater than the particles produced by an air explosion, and this circumstance exerts a decisive influence on the overall character of radioactive contamination.

After the violent perturbation caused by the explosion, quiets down, all the particles begin to gradually settle on the ground. At first the larger and heavier particles settle down and they are followed by the smaller ones. On the whole the process of fallout may occur over a rather long period of time after the explosion, depending on the meteorological and local conditions.

The length of time fallout may last can be calculated approximately on the basis of the known rate of fallout of small particles under the effect of terrestrial gravitation (Table 3).

Table 3

The Length of Time Fallout Lasts With Particles Descending From an Altitude of 12,000 meters

Diameter of particles mm	Length of time fallout lasts hours
0.150	2
0.075	8
0.035	40
0.015	170
0.005	over 1,000

As seen in Table 3 the length of time required for the bulk of the radioactive particles to descend to the ground after a ground explosion fluctuates from several hours to several days. If it is at the same time taken into consideration that the radioactive cloud is constantly shifted by the wind, it is possible for the cloud to have traveled several hundred kilometers while emitting fallout. As a result of this the entire territory over which the cloud has traveled will be contaminated. The density of radioactive contamination may be very great and dangerous to humans.

After the bulk of the radioactive substances have settled, small particles that remained in the cloud will continue traveling

with the wind for a considerable time. They also settle on the ground. The contamination they cause, however, is not very dangerous and in its nature it resembles the contamination that occurs following nuclear explosion in the air.

In the case of a ground explosion heavy contamination occurs near ground zero.

After a ground explosion the fireball touches the ground. An increase in the contamination of the ground surface occurs as a result of the settling of a significant amount of radioactive matter together with the largest particles of dust and earth raised into the air during the explosion. In addition to that contamination is also increased by the formation of radioactive substances in the ground under the effect of the neutron bombardment.

Underground nuclear explosions are distinguished by the heavy radioactive contamination of the ground they cause. This occurs because all the fission products and artificial radioactive isotopes mix and concentrate at ground zero. If some of the ground is expelled into the air by the explosion, the overall contamination picture becomes similar to contamination that is caused by a ground nuclear explosion.

In the case of an underwater detonation of a nuclear device a large mass of water is raised up in the air and a cloud of dense fog forms containing radioactive substances. As this cloud moves the radioactive substances descend and contaminate water areas or the territory over which it travels. The scales of this contamination, however, will be more limited than contamination caused by a ground explosion, since the bulk of radioactive products remains in the water in the area of the explosion.

Therefore the most dangerous radiation situation that may involve serious population casualties, is created as a result of ground explosions. In evaluating the peculiarities and the danger of contamination as a result of these explosions, it is necessary to take into account that areas directly adjoining ground zero and characterized by higher radiation levels, may at the same time be affected by other injurious factors: the shock wave, luminous radiation and penetrating radiation. High levels of radiation contamination complicate the conduct of emergency restoration, rescue and other operations directed at the liquidation of the consequences of an explosion.

Particular significance in the case of ground explosions, is acquired by the contamination of large areas along the path of the radioactive cloud formed by the explosion. These areas, as a rule, extend far beyond the zones in which the shock wave, luminous and penetrating radiation may cause injuries or damage. The high degree of contamination of these areas is not accompanied by any external symptoms and brings hidden danger to the people.

The conditions surrounding the formation of radioactive contamination along the path of the radioactive cloud, certain peculiarities and nature of such contamination, as well as some of the possible protective measures merit a more detailed examination.

As already noted the fallout of radioactive particles from the cloud formed by the nuclear explosion is a continuous process that begins from the time the cloud is formed and continuous until the cloud is completely dispersed. According to data furnished by foreign

scientists it is possible to consider that after a ground explosion about 50% of the early fallout settles in the direct vicinity of ground zero, while the rest of the radioactive substances are carried away by the cloud and contaminate territory as the fallout continues.

The overall direction and speed with which the radioactive cloud moves is primarily determined by the nature of wind currents at various altitudes above the earth's surface. As the cloud moves and the fallout continues the contaminated area gradually expands. As a result there forms a large contaminated zone which is usually called the radioactive cloud trail. The trail, as a rule, has the shape of an ellipse extended in the direction of the wind, whose long axis is conditionally called the trail axis (Fig. 2a). In some cases, under the influence of changing wind currents and the terrain relief, as well as because of other factors, the trail may change its shape and acquire somewhat different outlines (Fig. 2b).

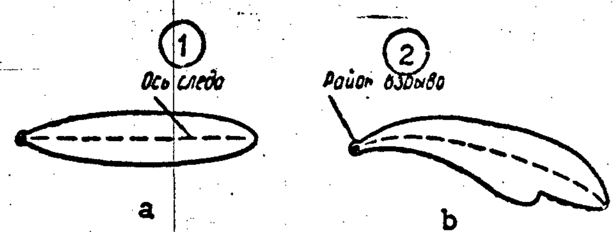


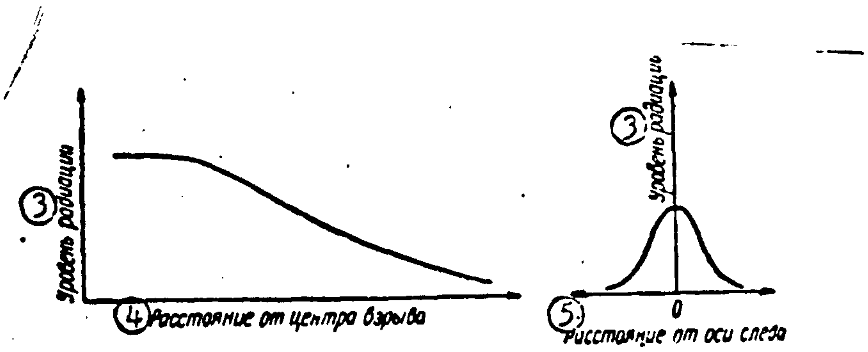
Fig. 2. Approximate trail left by the radioactive cloud.

Legend: 1 -- Trail axis; 2 -- Ground zero.

The dimensions of the trail left by the radioactive cloud depend on the type of explosion, the caliber of the detonated nuclear device and wind velocity. With an increase in the caliber there is an increase in the length and width of the trail. This occurs primarily as a result of the formation of a large amount of radioactive substances and the position of the cloud at higher altitude. An increase in wind velocity leads to an increase in the length of the trail.

Radioactive substances along the cloud trail are distributed unevenly (Fig. 3). A certain regularity is, however, observed in the distribution of radioactive substances which consists of the fact that the level of radiation gradually decreases along the trail axis in the direction away from ground zero. At the same time the heaviest radioactive contamination always occurs along the trail axis and gradually decreases in the direction of the side boundaries of the trail. In some cases possible deviations from this regularity depend on the local conditions. Under the influence of the wind, for example, there may be a stronger contamination of the windward sides of hills and structures. The nature of contamination may change also under the influence of rain, snow, fog and other factors.

The general approximate dimensions of the area of radioactive contamination, that is formed as a result of ground nuclear blasts, may be determined on the basis of data furnished in Tables 4 and 5.



1 2

Fig. 3. Distribution of radioactive substances along the cloud trail axis.

Legend: 1 -- Along trail axis; 2 -- Across the trail axis; 3 -- Radiation level; 4 -- Distance from ground zero; 5 -- Distance from trail axis.

Table 4.

Radioactive Contamination of the Terrain Following a 20 Kiloton Ground Explosion With a Wind Velocity of 24 kilometers/Hour (One Hour After the Explosion)

Radiation level (roentgens/hour)	Length of trail, kilometers	Width of trail, kilometers
3,000	1.6	0.5
1,000	3.7	1.1
300	8.3	1.9
100	18.5	2.9
30	35.0	4.5
10	80.0	8.1

Note: Data for 30 and 10 roentgens/hour apply to the time at the end of trail formation.

As indicated in Table 4 the area of radioactive contamination with a radiation level of 1,000 roentgens/hour is equal to about three square kilometers, the area with a radiation level of 100 roentgens/hour is about 42 square kilometers, while the area with a radiation level of 10 roentgens/hour is over 500 square kilometers in size. With a nuclear explosion of several megaton, under the same conditions the area covered by the radioactive trail of the cloud will be many times greater.

The approximate data in Table 5 show that the area of radioactive contamination following a single high power nuclear explosion may cover tens of thousands of square kilometers. Therefore it should be assumed that such a large area of contamination may encompass many cities, populated points, enterprises and rural areas.

Table 5.

Approximate Dimensions of the Radioactive Cloud Trail 18 Hours After An Explosion of Several Megatons With a Wind Velocity of 24 Kilometers/Hour

Radiation level, roentgens/hour	Length of trail, kilometers	Width of trail, kilometers
100	95	15
30	190	35
10	Over 300	Over 60

The scales and the degree of danger presented by radioactive contamination may be evaluated with sufficient accuracy by analyzing the results of an experimental thermonuclear explosion made by the US in the Bikini Atoll area in 1954, the information on which was published by the American Atomic Energy Commission.

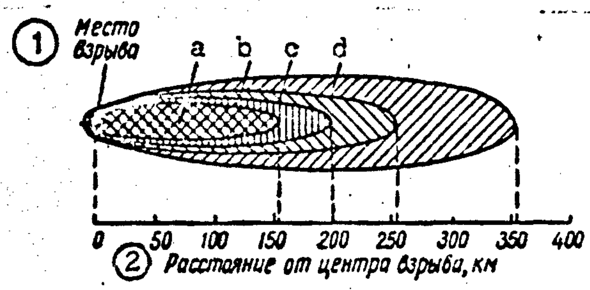


Fig. 4. Contaminated zone occurring after a thermonuclear explosion made by the US in the Bikini Atoll area on 1 March 1954. The letters designate the area where the radiation dose in a 36 hour period came to:
a) 2,300 roentgens; b) 1,000 roentgens; c) 500 roentgens; d) 300 roentgens

Legend: 1 -- Ground zero; 2 -- Distance from ground zero, kilometers.

The size of the trail left by the radioactive cloud produced by this explosion and the cumulative doses of radiation that could have been received by unprotected people within the contaminated area over a 36 hour period are shown in Fig. 4. As a result of this explosion a cumulative dose of 300 roentgens could have been received by people along the cloud trail about 350 kilometers in length and in an area equal to about 15,000 km^2. A cumulative dose of 50 roentgens over the same period of time could have been received by people within an area in the order of 60,000 km^2.

It is apparent that during the radioactive fallout from the

cloud produced by a nuclear explosion, there also occurs the contamination of the air, water sources, vegetation and the like in addition to the contamination of the terrain and various local objects.

The heaviest contamination of the air will be observed during the fallout of radioactive substances from the cloud. Significant contamination of the air, however, may also occur after fallout terminates, since the radioactive particles on the ground, on the local structures and on vegetation may be again stirred up into the air by wind, together with ground dust. This should be particularly anticipated during dry, windy weather on highways with heavy pedestrian and vehicular traffic.

Under such conditions the presence of people without protective equipment in the contaminated atmosphere may lead to the penetration of radioactive substances inside their organisms through their respiratory organs. Contaminated food and water constitute the main sources of internal irradiation.

An important peculiarity of radioactive contamination is its inconsistent nature and a perceptible decrease with time as a result of the process of continuous decay of radioactive substances.

The complex mixture constituting the radioactive residue of a nuclear explosion includes short and long-lived radioactive isotopes. Therefore the overall rate of their decay is subordinated to more complex laws than those applying to individual isotopes.

It was experimentally established that the drop in radiation levels is approximately in reverse proportion to the time that elapses from the moment of the nuclear explosion, and is subordinated to the following ratio: radiation levels decrease by ten times if the time, that elapsed since the moment of explosion, increases by seven times (Table 6).

The practical calculation of the drop in radiation levels along the cloud trail over any interval of time elapsing after the nuclear explosion may be calculated using the following empirical formula

$$P = P_o\left(\frac{t}{t_o}\right)^{-12}$$

where P is the radiation level, roentgens/hour, that occurred in the given area of the terrain after the period of time, t, of interest to us, that elapsed since the explosion; P_o is the radiation level, roentgens/hour, measured on the terrain t_o after the explosion; t_o is the time, hours, that elapsed between the moment of explosion and the measurement of the initial radiation level on the terrain, or the time at which contamination occurred; it is the time, hours, that elapsed after the explosion, at which we are interested in finding the radiation level.

Knowing the radiation level for the given area for a certain period of time that elapsed after an explosion, and using the cited formula, it is possible to trace the drop in radioactive contamination for any period of time of interest to us.

Table 6.

Change in Radiation Levels Along the Trail of the Radioactive Cloud With Time

Time after explosion, hours	Radiation level, roentgens/hour
1	100
7	10
49	1
343	0.1
2,401	0.01

In the process of a natural drop in contamination the decay of short-lived isotopes ends sooner, and with time only long-lived isotopes remain in the contaminated area. Their number, however, steadily decreases.

The time required for the natural decontamination of the territory primarily depends on the amount of radioactive substances on it, i.e. on the degree of radioactive contamination. With time the radioactive contamination drops simultaneously through the area covered by the trail, and, if we don't take into account the possible influence of local and meteorological conditions in some areas, first to become safe are the areas along the edge of the cloud trail, which have a lower radiation level. Thus the overall contaminated area gradually shrinks.

Out of what we have said about the peculiarities of radioactive contamination along the cloud trail it is possible to conclude that the danger of people in the contaminated zone becoming injured will be uneven and will increase in the direction of ground zero and areas around the cloud axis. In this connection different protective measures must be taken in different areas.

II

PROTECTION AGAINST THE INJURIOUS ACTION OF RADIOACTIVE SUBSTANCES

Methods and Means of Achieving Protection Under Conditions of Radioactive Contamination

It was already mentioned that radioactive substances may have an injurious effect on people as a result of either external irradiation or as a result of the penetration of the radioactive substances inside the person's organism with food, water or air. Consequently general measures of antiradiation protection must consist of the finding and use of the most easily accessible and reliable means and methods protecting people against such action.

It should be considered that with the existence of large radioactively contaminated areas there are two main methods of protecting people. One of them is the evacuation of the population of areas which are threatened with radioactive contamination, the other method is the conduct of protective measures on the spot, directly in the contaminated area.

The protection of people against the injurious action of radioactive substances by means of evacuation at first glance appears to be quite simple and efficient. Protective measures in this case are based on the fact that the contamination of the terrain after the explosion is a slow process as the cloud moves and it is considered that the direction in which the cloud will move may be forecast ahead of time thus determining the most dangerous zones of contamination. People will therefore leave these danger zones ahead of time. At the same time a careful study of this question indicates that in reality the situation is much more complicated than it appears at first glance.

American specialist Davidson, in expressing himself against evacuation as a protective method, states that the possibility of a forecast, foretelling the direction and speed with which the radioactive cloud will move, is now rather limited and that it is impossible to accurately determine ahead of time the zones that will be contaminated and the degree of contamination. The second obstacle to the execution of this protective method he believes to be the possibility

of a mass utilization of nuclear weapons, as a result of which there may form not individual contaminated zones but broad continuous zones of contamination, which will not permit the determination of safe areas for the evacuees. Finally, a great difficulty in the correct organization and execution of evacuation of the population will be the insufficient certainty and clarity of the situation which occurs in the initial period after a nuclear attack.

Calculations indicate that radioactive clouds move rather fast with speeds of tens of kilometers an hour. Therefore even with an accurate forecast of the direction and speed of movement of the cloud produced by the nuclear blast, the reserve of time required for the organized warning of the population concerning the forthcoming danger, the preparation and assembly of people for evacuation, loading the means of transportation, and finally, time for their transportation to safe areas, will be very limited.

In addition to that under the conditions of a mass utilization of nuclear weapons it is impossible to expect any guarantee that the evacuees will not be injured enroute to safe areas, or that the destination of the evacuees will not be the location of one of the next explosions. At the same time mass evacuation is often associated with difficulties of supplying the people with food, water, housing and medical service. As a result the evacuees may find themselves in an even worse situation than those who remained in the contaminated area. Evacuation, therefore, cannot be accepted as a reliable protective measure. It may be used only in exceptional cases. Protective measures on the spot are most reliable and yield adequate results.

For protection against external irradiation people in contaminated territory may utilize various structures and buildings with sufficiently thick walls and roof, which would stop or weaken radioactive radiation. If purified air is fed into these structures, the people at the same time are protected against the penetration of dust like radioactive substances into their respiratory organs.

The general measures of protecting the people against the penetration of radioactive substances inside the organism is much more complicated. In addition to the direct protection of the respiratory organs, additional measures are required to prevent the contamination of food, water and agricultural animals.

Special shelters, wooden shelters, dugouts and basements, cellars, mines, residential and production buildings.

Shelters are capital structures out of concrete, reinforced concrete or stone that are built specially for the protection of people against all weapons of mass destruction. These shelters include filter-ventilation or regeneration equipment for the purification of the air inside the shelter. A heating system is provided along with running water, sewage disposal and illumination.

The simplest type of shelter is a slit trench (Fig. 5) — a narrow trench around two meters deep, equipped with entrances and doors. In order to prevent cave ins the walls of the trench are lined with poles, brushwood or boards. On top the trench is covered with logs, poles, or boards and covered with a layer of earth. In order to keep

water from seeping through the roof, a layer of clay is poured over the roof before the layer of earth is piled on. Benches are constructed inside the trench.

Dugouts (Fig. 6) are generally similar to slit trenches. They are, however, more roomy and comfortable. Bunks are built in them for sleep. During the cold time of the year stoves are installed in the dugouts.

Shelters, such as slit trenches and dugouts, may be constructed out of various building elements (slabs, large diameter pipes, beams, etc), which are now used on a large scale in industrial and residential construction.

By contrast with shelters, slit trenches, dugouts, cellars, basements and other such types of shelters do not have equipment for purifying the air or sanitary facilities. Therefore these types of shelters cannot be occupied for very long.

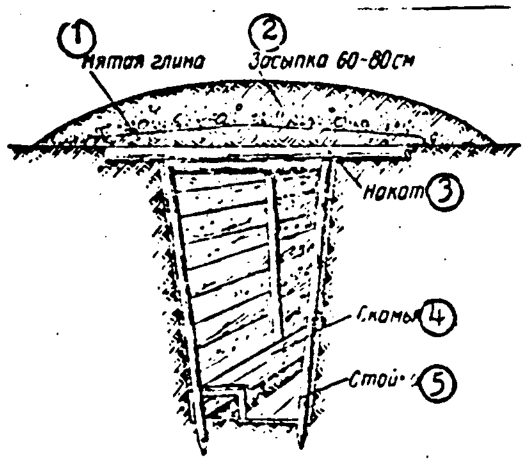


Fig. 5. A slit trench.

Legend: 1 -- Clay; 2 -- A 60-80 cm layer of earth; 3 -- Decking; 4 -- Bench; 5 -- Prop.

The protective properties of the enumerated structures are not the same. They offer varying degrees of protection against external irradiation and the penetration of radioactive substances inside the shelters. The protective properties of structures against external radiation depend primarily on the material out of which they are built, and on the thickness of the walls and roofs.

The quality of materials is usually evaluated on the basis of their ability to weaken gamma radiation which has the greatest penetrating capacity. The decisive role here is played by the atomic weight and the density of the material. The denser the material the better it blocks radiation.

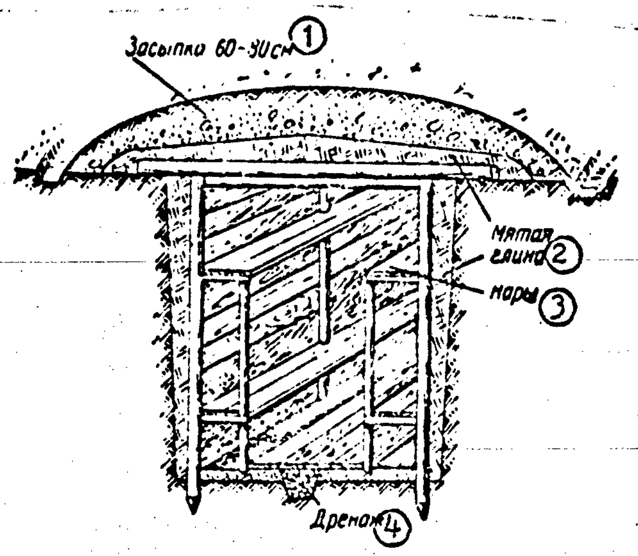


Fig. 6. A dugout.

Legend: 1 -- A 60-80 cm layer of earth; 2 -- Clay; 3 -- Bunks; 4 -- Drainage ditch.

An idea ofthe protective property of various materials is given by the half-value layer. The half-value layer is a layer which decreases the initial intensity of the radiation penetrating it by one-half, i.e., it filters out half of the gamma quanta traversing it.

The smaller half-value layer the better the protection given by the material. Some materials have the following half-value layers (in centimeters):

Lead...........	1.5-1.8
Iron............	2-3
Aluminum........	6-7
Concrete........	7-10
Brick...........	12
Lumber..........	25
Earth...........	12-15

As we see from the cited data lead, the densest material, serves as the test block against gamma radiation. This expensive and critical material, however, is used for protection only in laboratory and production conditions. Only conventional building materials may be used in the construction of shelters: brick, concrete, earth, and wood which do not offer as good a protection against radiation as lead and iron. This shortcoming, however, may be compensated by increasing the thickness of the walls and roofs made out of these materials. Thereby it is always possible to achieve the desired attenuation of the radiation.

The attenuation of radiation depending on the thickness of the wall is shown in Fig. 7. The wall is conditionally split into three layers each of which decreases radiation by one-half.

As we see, after penetrating the first layer the gamma beam is decreased by one-half, after penetrating two layers -- it is decreased by four times and after passing through all three layers the radiation is decreased by eight times.

By significantly increasing the wall thickness is it possible to achieve practically complete attenuation of radiation. It is, however, impossible to fully judge the protective properties of the structures on the basis of only the material and thickness of the walls. These properties also depend on the design of the structure. Doors and windows, for instance, decrease the protective properties of the structures. The structures may protrude above the surface of the ground or may be entirely underground. This also has a very great significance. Underground structures possess better protective properties since the surrounding layers of earth, in addition to the walls, will considerably decrease the radiation.

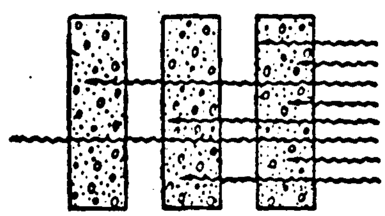


Fig. 7. Attenuation of radiation by protective walls.

The protective properties of various structures as a whole are generally evaluated with the aid of the radiation attenuation factor. This factor indicates the number of times that the radiation is less inside the shelter than outside. For example, if the attenuation factor of a shelter is equal to 10, this means that a person inside such a shelter will receive a dose ten times smaller than a person who is out on the street.

The attenuation factor for certain structures, as well as inside an automobile are given below.

Slit trench, dugout..................	40
Single story stone house.............	10 - 15
Single story wooden house............	3 - 5
Basements in stone houses............	200 -300
Automobiles..........................	2

Shelters, mines and mining excavations attenuate radiation by several hundred times more, i.e., block radiation almost completely.

We should consider the protective properties of buildings in somewhat more detail. Data on a single story house were given above.

Rooms on the upper floors of multiple story buildings, however, have a much greater attenuation factor. This is explained by the fact that there is quite a large distance between them and the ground where the bulk of radioactive substances are located, as a result of this the radioactive radiation is considerably weakened by the layer of air.

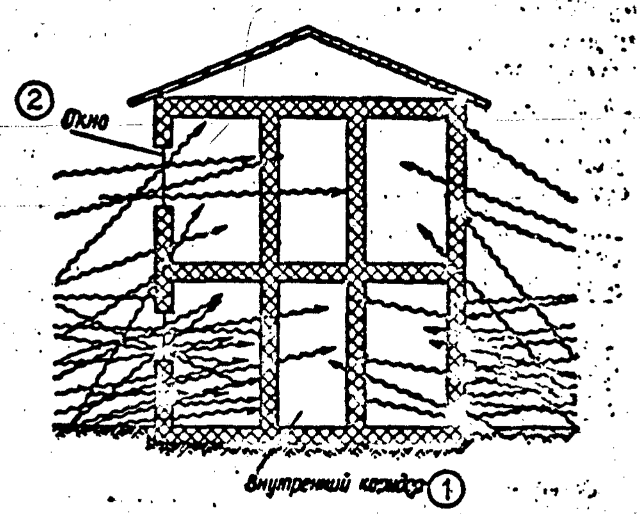


Fig. 8. Protective properties of buildings.

Legend: 1 -- Interior corridor; 2 -- Window.

An exception may be the topmost floor of a building because on its roof some radioactive substances may accumulate. Therefore the attenuation factor of the topmost floor of a building is not too different from the factor pertaining to a single story house.

Various rooms and areas inside the buildings also have different protective properties.

Areas inside buildings which have many doors and windows will have smaller protective properties. It is best to use interior areas in the buildings for shelter, for example, corridors, or, in an extreme case, rooms with the least number of windows and doors. The comparative characteristics of the protective properties of exterior and interior areas of building areas are shown in Fig. 8.

The protective properties of the buildings may be increased substantially but sealing the windows and all non-essential doors with sandbags or boxes with sand (earth).

A slit trench or a dugout excavated inside a building provide good protection. This is easy to do, for instance in rural buildings. In this case the high protective properties of the slit trench are combined with the conveniences of a dwelling.

Sufficiently pure air must be ensured inside the protective structures. This is achieved by the sealing of all ventilation ducts and openings capable of admitting radioactive dust. The walls and

ceilings of the structures as a rule are sufficiently dense and therefore are able to prevent the penetration of radioactive dust.

In dugouts, cellars and other structures radioactive substances may penetrate through doors, and through cracks in the doors and in the door frames. In the basement dust will also penetrate through ventilation ducts. Radioactive dust may penetrate inside the buildings through windows, doors, air vents and exhaust pipes, dormer windows, etc.

In order to increase the air tightness of structures all cracks in doors and door frames are sealed, vents and other openings are closed, and cracks in window frames are caulked or pasted over. Cracks at the point where the doors adjoin the door frames may be sealed with weather stripping out of rubber or some other material.

It is necessary to take into consideration the fact that air tightness, in addition to its advantages, also has certain disadvantages. Air in an air-tight occupied compartment without air purification facilities soon deteriorates: there occurs an increase in carbon dioxide, as a result of which the length of time that the people may remain in such compartments is sharply curtailed. In order to prevent this it is possible to leave several air vents unsealed in the compartment, merely covering them with several layers of fabric. The fabric will act as a kind of filter purifying the air flowing into the compartment. These vents must have lids which can be periodically removed to ventilate the compartment. If there are no air vents the compartment may be ventilated by opening the door. It is, however, important to keep the door opening covered with a piece of fabric.

In order to provide a final evaluation of the various types of protective structures, it is necessary to take the following important circumstance into account. Under conditions that would be created in a nuclear war the structures must provide protection not only against the effects of radioactive substances, but also against other elements of the nuclear explosion, particularly against the shock wave. Therefore in selecting a structure it is necessary to consider not only its attenuation factor but also its stability should a shock wave occur.

In protecting people under the conditions of radioactive structures. Those in shelters cannot remain there continuously for long periods of time. For various reasons they will be compelled to leave the shelters and remain on contaminated terrain in a contaminated atmosphere for a certain period of time. In this connection special devices are required for personal protection against radioactive injury. These devices are called individual protective equipment.

Unfortunately the individual protective equipment currently in existence does not provide complete protection against external irradiation since it is practically impossible to produce the type of clothing and suits that would block gamma radiation. Therefore the individual protection of a person is only partial and consists of the protection of the respiratory organs and the skin surface against contamination by radioactive substances.

Various devices may be used for the individual protection of people against radioactive contamination. Gas masks, respirators,

dustproof masks and various bandages are used to protect the respiratory organs. The GP-4u gas mask serves to protect the adult population. DP-6 gas masks are used to protect children in the 12-15 year age bracket. While children of the pre-school and younger age group (from one to twelve years of age) use the DP-6m gas mask. The infant KZD-1 cell is used to protect infants under one year of age. Gas masks and the infant protective cell protect not only against radioactive dust but against toxic substances and bacteriological weapons as well.

Industrial gas masks, and many types of respirators which are currently used on a large scale in the chemical, mining, metallurgical and other branches of industry where air is polluted with harmful substances, provide a reliable means of protection against radioactive substances.

The dustproof fabric mask may be used successfully for protection against radioactive dust. This mask is easily made at home out of various kinds of fabric.

If none of the above devices are available it is possible to use cotton-gauze bandages, or bandages made out of several layers of fabric. In extreme cases towels, scarves kerchiefs and other items may be used.

In order to protect the skin surface it is also possible to use handy pieces of clothing in addition to special clothing produced by industry (overalls, suits, boots, socks and gloves). Work overalls, production clothing and sports suits may be used for protection. If such clothing is not available ordinary clothing is used: raincoats, smocks, overcoats, and the like. When moving over contaminated territory it is necessary to wear a cape.

Hoods, kerchiefs or scarves may be used to protect the head and body. The feet can be protected with rubber boots, snow boots, or, if they are not available, with leather boots or shoes with galoshes. The hands are protected with rubber or leather gloves or fabric mittens (gloves).

The clothing worn by persons on contaminated territory must be completely buttoned up. The pants and sleeve cuffs should be secured around the wrists and ankles with shoelaces or string.

The Order in Which Protective Measures Are Carried Out

The protection of the population must, apparently, be organized so that on the one hand the people will not receive radiation injuries, and on the other, their continued survival and subsequent return to normal life must be ensured. Therefore in organizing the protection of the population it is important to correctly determine the amount of time to be spent by the people in shelters, the manner in which individual protective equipment is to be used and the rules of conduct under conditions created by radioactive contamination. All this may be done by radiation monitoring and determination of the nature of radioactive contamination.

An approximate idea about the consequences of irradiation is provided by the size of the doses cited above. The Rekomendatsii

NKRZ SShA (Recommendations of the US National Committee on Radiation Protection) published in the USSR by the Publishing House of the Main Directorate for Atomic Energy Utilization at the Council of Ministers USSR, indicates that in wartime it is permissible for people to receive irradiation doses higher than those allowed in peacetime. This is explained as follows.

The consequences of radioactive irradiation of humans may be conditionally divided into three categories: immediate, remote and genetic.

Immediate consequences consist of radiation sickness of varying severity occurring after comparatively heavy irradiation doses. These consequences involve loss of ability to work and requirement for medical treatment.

Remote consequences consist of an increase in the incidence of malignant malignancies, and the like. They lead to an immediate loss of working ability after irradiation and may be manifested throughout the person's lifetime.

Genetic consequences are consequences that are manifested in the subsequent generations of the irradiated person.

The permissible irradiation norms for humans in peacetime are established so as to prevent any harmful consequences of such irradiation. Under the complex and difficult wartime conditions, however, it becomes necessary to disregard remote and genetic consequences. Therefore in wartime it is important to prevent only the immediate consequences resulting from the irradiation of humans.

In determining the time spent by people in shelters and the rules of conduct it is important to take into account the inconstancy of radioactive contamination. As pointed out above radioactive contamination drops steadily with time. Consequently the danger of injury to humans also decreases, i.e., the size of the doses that may be obtained in each subsequent interval of time decreases.

It is considered that around half of the cumulative dose that people may receive on contaminated territory, is received in the first 24 hours. On each subsequent day the dose will be smaller. This is seen in the graph (Fig. 9) compiled on the basis of American data. This graph shows the accumulation of doses with time. The vertical line shows the size of the doses in percent accumulated over individual segments of time, while the horizontal line shows the time from the start of contamination.

According to the graph the dose accumulated over the second 24 hour period will be much smaller than the one accumulated in the first 24 hour period. During the third 24 hour period the dose will be even smaller and so on. Therefore contamination presents the greatest danger during the first several days, and especially during the first 24 hours after contamination. Thus the greatest protection must be afforded specifically in that early period of time. Even during the first 24 hours the danger of injury is not the same. In the first six hours, as we see from the graph (Fig. 9) 60% of the two day dose is accumulated, during the second six hours 16% of the dose is absorbed, during the third six hour period 6% of the dose is accumulated and in

the fourth six hour period % of the cumulative dose is absorbed. Hence we see that the greatest danger during the first 24 hours of contamination occurs in the first six hours. Thus it is possible to consider that people may receive heavy irradiation doses during the very first few hours after contamination occurs. This leads to the important conclusion that shelter must be sought as soon as the threat of radioactive contamination develops.

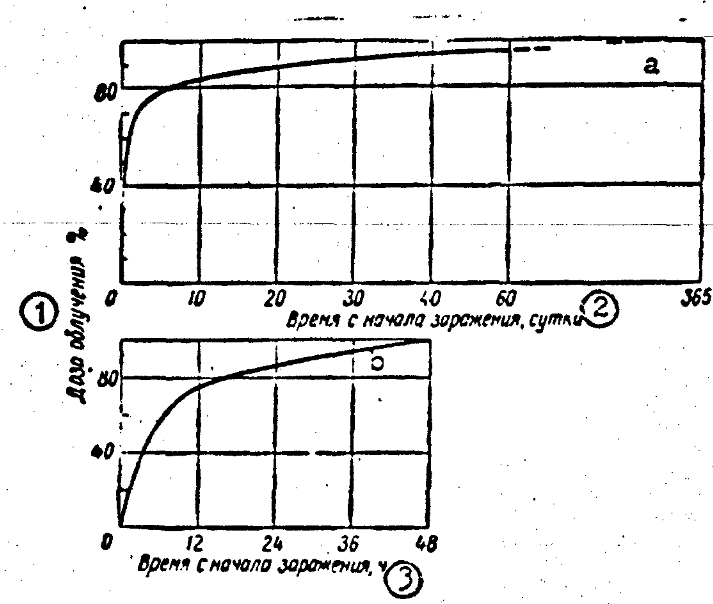


Fig. 9. The accumulation of an irradiation dose during a prolonged stay on contaminated territory (a) and over a two day period.

Legend: 1 -- Irradiation dose, %; 2 -- Time from start of contamination, days; 3 -- Time from start of contamination, hours.

In establishing the rules of conduct for the population it is necessary to establish the overall method (place and time) for using individual protective equipment.

Individual protective equipment must be used in cases when there is danger of radioactive substances penetrating into the respiratory organs or settling on the skin. These conditions are most likely to occur when there is a large amount of radioactive substances in the air or on objects with which a person comes in contact.

The largest amount of radioactive substances is found in the air during fallout from the radioactive cloud produced by the atomic explosion. This period begins approximately from the moment the cloud approaches to a certain point and ends after the cloud drifts past that point. The start of radioactive fallout may be determined with

the aid of dosimetric instruments. Radioactive fallout at a certain point on the terrain may last for from ten minutes to one-two hours. A longer fallout period is also possible. According to the Japanese fishermen, for example, who were trapped under a radioactive cloud produced by an American nuclear blast of 1 March 1954, the "ashes," as they called the radioactive dust, fell on them for four to five hours.

Later radioactive substances may again be stirred up into the air from the ground and contaminated objects. The degree of air contamination in this case will depend on the wind velocity and on the nature and degree of terrain contamination. A strong wind may stir up much dust. Ground wind is particularly dangerous in this respect.

It may be said that the contamination of the air will be most dangerous during the first period, i.e., when external irradiation presents the greatest danger. Radioactive substances may be stirred up into the air by vehicular traffic, by pedestrians walking along dusty roads, as well as by various dust producing work such as the clearing away of ruble, construction, plowing of dry soil and the like. Radioactive substances may settle on the skin even on contact with contaminated objects.

The possibility of contaminated dust penetrating inside the shelters and sealed buildings is very limited. Therefore it is possible to remain in these shelters and buildings without wearing individual protective equipment.

During the initial and most dangerous period, individual protective equipment should be used by anyone out on the street.

Later, for the next several days, this equipment must be used only during dry windy weather or in doing work that raises dust, or if it is necessary to handle contaminated objects.

The conduct of people, depending on the situation that develops, should be examined using different examples.

Fig. 10 gives a schematic representation of the radiation situation in two populated points situated in different zones of radioactive contamination. The diagrams show the size of the doses that people may receive out in the open per day.

At point M radiation doses that may be received by people even on open terrain, are not great. Therefore there is no need to stay in shelters. It is sufficient for people in that zone to remain the first 24 hours in ordinary buildings. Those living in wooden houses (radiation attenuation factor is equal to 3) will receive a radiation dose of 16 roentgens during the first 24 hours. On the second day, even if the people spent 12 hours outdoors and 12 hours in their houses, they will receive a dose of five roentgens, while on the third day they will absorb three roentgens. People living in stone houses (attenuation factor of ten) will receive even smaller doses of radiation.

As we see the radiation doses received by the population are harmless under these conditions. Therefore the above conduct may be recommended for the protection of the population in zones where the radiation situation is similar to the one at point M.

At point H the people will be exposed to a greater danger. The buildings there will not provide adequate protection. People in wooden buildings may receive a dose of 230 roentgens on the very first day, the dose that would be absorbed by persons in stone buildings would

amount to 70 roentgens. Therefore residents of populated point H must occupy protective structures.

The people must remain in the shelters only during the initial, most dangerous period of contamination. These shelters must have a high attenuation factor. After initial radiation level drops the people may leave the shelters and move to buildings which, if the radiation levels are low, provide satisfactory protection and where the living conditions are much more comfortable than in the shelters.

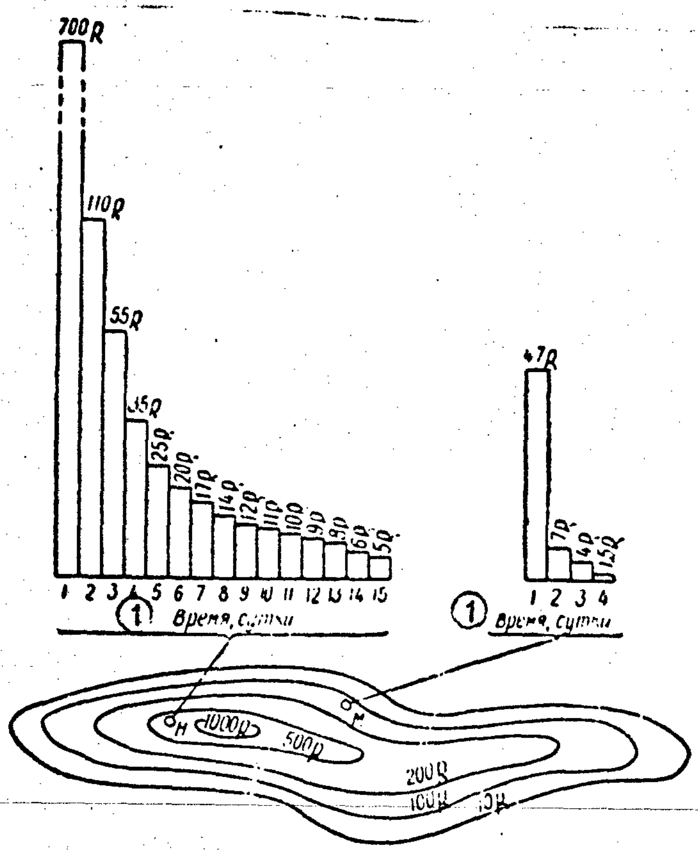


Fig. 10. Radiation doses in contaminated zones (a variant).

Legend: 1 -- Time, days.

Residents of populated point H must remain in the shelters for only two days, after which they may move to buildings. It should be noted that continuous presence in shelters for two days is quite uncomfortable. Therefore those in shelters without sanitary facilities which are not suitable for prolonged occupation may leave the shelters for brief periods. The time that may be spent outdoors should

not exceed 20-40 minutes every 24 hours.

Eventually the population may return to normal life and work providing dosimetric control is maintained. Under these conditions people living in wooden houses at point H will receive radiation doses of 22-25 roentgens over a four-five day period, while those living in stone houses will receive even a smaller dose.

There may be zones along the trail of the radioactive cloud, where contamination would be higher than at populated point H. There the people will have to remain in shelters for a correspondingly longer time. The time that may be spent by people outdoors will also increase, and a more stringent observance of precautionary measures in handling contaminated objects will be mandatory.

It is understandable that the strict observance of set rules of conduct for a prolonged period of time is very difficult and involves many deprivations for the population. The life of people in such zones may be facilitated by their temporary resettlement to uncontaminated or mildly contaminated zones. Such a resolution of this question is possible for that part of the population which is not involved in vital production work.

Such resettlement, however, must not be confused with evacuation of the population from zones which are threatened by the radioactive cloud, and, whose feasibility was discussed earlier. The resettlement of people from zones which will remain contaminated for a long period of time may be carried out only after a sufficiently full determination of the situation and after a drop of the contamination level of the area through which the people will be moved. The people must remain in shelters until resettlement begins.

As we see the protective measures and the conduct of the population may be quite different in the various contaminated zones, depending on the situation that develops. Concretely they will be determined by civil defense agencies depending on the dosimetric data and local conditions. The population will be informed of the various measures by signals and orders.

Rules Governing Conduct Under Conditions Created by Radioactive Contamination

The successful protection of people against the injurious action of radioactive substances depends on many factors. Protection is first of all assured by knowledge of the harmful effects of radioactive radiation, by an ability to select the most reliable means and methods of protection under given conditions, as well as by the timely organized implementation of protective measures.

The scope and nature of protective measures, as a rule, is determined by local authorities or by the recommendations issued by the republic, kray, oblast and city civil defense agencies.

Under all circumstances, however, a very important role belongs to the population itself, which must take direct measures of protection and observe corresponding rules and norms of conduct. First to be resolved are the most important questions concerning the preparation of

necessary facilities to protect the people and determination of the manner in which they are to be used.

In a number of cases it will become necessary to supplement the reserve of collective protective facilities at the same time ensuring the timely realization of the proposed measures by the maximum possible adaptation and utilization of the simplest shelters such as slit trenches, dugouts, basements, cellars, underground tunnels, trenches and other such structures.

All the main work that must be done in the adaptation and equipment of the shelter, sealing of the shelters, reinforcement of roofs and increasing the protective properties of the shelters can be carried out only with the direct participation of the population. The organization and provision of the people with individual protective equipment in some cases will also involve the active participation of the population. If there is not enough gas masks and special types of protective clothing their supply must be supplemented by simple and handy protective means: masks, bandages, overalls, cloaks and other items that can be made by the population.

It is difficult to believe that it will be possible to determine the time which will have to be spent in shelters before the actual attack. Therefore we also have the very complex task of providing the people with food and water sufficient to last them throughout their stay in shelters in the contaminated zone. In populated points the task of protecting stores of food in warehouses and in the trading network is resolved by the introduction of mandatory centralized protective measures.

This circumstance, however, does not mean that after the warning is given of a possible nuclear attack or radioactive contamination, the population will not have to take care of its own individual food and water stocks sufficient for several days. Such stocks must be prepared ahead of time and be reliably packaged and stored so as to prevent them from radioactive contamination.

The population will be informed of the threat of radioactive contamination by means of specially established signals that will be given by civil defense agencies. After these signals are given the entire population, with the exception of workers and employees at the enterprises, must immediately proceed to the shelters. Those who remain at work must act in accordance with instructions and orders given by the administration.

What should the further conduct of the population be?

As a rule, during the first few hours, and in some cases days, the population may not have any information on the radiation situation or data relative to the degree and nature of the radioactive contamination of the area. These data may be received only after radiation reconnaissance by civil defense reconnaissance units equipped with instruments, protective clothing and transportation facilities. In addition to that, after receiving data on the radioactive contamination from the reconnaissance units, a certain amount of time will be required to inform the population and also to prepare and transmit practical recommendations concerning the further rules of conduct. It

may take a long time to accomplish all this if the radio broadcasting and other communication facilities are destroyed. In such a case the population will, apparently, have to be informed through special messengers. Such cases are particularly possible in areas hit by the shock wave.

The population, uninformed with regard to the radiation situation, must remain in shelters and observe strict precautionary measures, considering the given area to be highly contaminated, until instructions and orders are received from local authorities and the civil defense headquarters.

Above it was already mentioned that the people may leave shelters for brief periods of time. It should be noted, however, that it is possible to leave the shelters only in cases of extreme necessity providing all protective measures are observed. A primary consideration should be the factor of time that elapsed since contamination occurred. The graph in Figure 9 confirms that the longer the people stay in the shelters the smaller the dose they receive on emerging. Consequently emergence from the shelter should be delayed as long as possible, and, if the situation permits, the people should remain in the shelter at least the first 24 hours.

When leaving the shelter it is absolutely necessary to be wearing individual protective equipment to protect the respiratory organs and the skin. On returning to the shelter it is important to observe precautionary measures since the protective equipment is contaminated. Before entering the shelter it is necessary to remove radioactive substances that have settled on the clothing. Radioactive dust should be removed by shaking out and sweeping down the clothing. Particular attention must be devoted to the decontamination of footwear. Dust may be removed from the shoes by sweeping or wiping with a damp rag.

It is necessary to remember that shelters not equipped with filtration and ventilation facilities, have to be periodically ventilated by opening doors or air vents. The length of time that the vents or doors are left open is determined by the way the shelter occupants feel themselves, as well as by the conditions under which they are. In this case as well ventilation should be delayed for as long as possible after contamination occurs.

Despite the fact that ventilation must be carried out through air vents or doors covered with fabric curtains, after they are closed it is feasible to clean the shelter with damp brooms and rags in order to clear away any radioactive dust that may have penetrated.

After receiving special permission in several hours and sometimes in several days the shelter occupants may leave the shelters and move to buildings providing certain rules of conduct are observed. During that period the time that may be spent outdoors must be curtailed in accordance with the intensity of radiation outdoors. The doors and windows of the building should be kept closed. When outdoors it is important to wear individual protective equipment and on returning to the building the people must observe the same precautionary measures that were recommended for re-entering the shelter.

Finally, after a certain period of time limitations concerning

the time that may be spent outdoors are lifted. Even after a significant drop in the contamination a certain amount of radioactive substances remain on the ground, the vegetation as well as on buildings and various other structures. The bulk of the remaining radioactive substances will be mostly the long-lived isotopes, the most dangerous of which is Strontium-90. During that time the main danger will consist of the penetration of radioactive substances inside the organism with food and water. It is impossible to ignore this fact, and people living on such territory will have to observe certain precautionary measures when handling contaminated objects.

One should be particularly careful not to use food and water that were not checked for contamination. The length of time during which such precautionary measures must be observed may amount to weeks and, in some cases, to months.

Thus the time spent by people on contaminated territory may be broken down into three periods: the first period -- mandatory stay in shelters, second period -- stay in buildings with limited time spent outdoors, and the third period -- when the limitations on the time that may be spent outdoors are lifted, but it is still necessary to observe precautionary measures when handling contaminated objects.

The length of each of these periods may be determined only by civil defense agencies on the basis of data obtained through radiation reconnaissance and a study of the existing conditions.

In addition to the observance of rules governing the time that is to be spent in shelters as a measure of protection against the effects of radioactive substances, an important role is also played by other measures in which the population must participate or conduct them independently. Such measures first of all include decontamination. Decontamination consists of the removal of radioactive substances from skin surfaces. It may be partial or complete. Partial decontamination involves the removal of radioactive substances from the exposed skin surfaces, the hands, face, and neck by washing them with soap and water, or by wiping them with a moist towel, handkerchief, rags or cotton tampons. Such decontamination must be carried out on entering the shelter or building after being on contaminated territory. The hands must be washed and wiped before each meal. Complete decontamination consists of washing the entire body with hot water and soap under a shower or in the bath house. As a rule this is done after the people leave the contaminated zone.

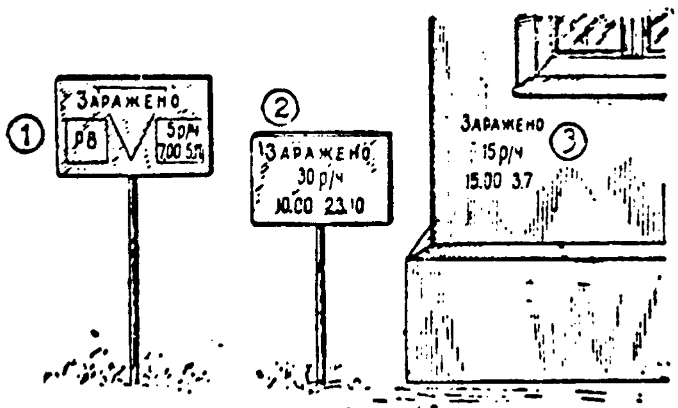
The population will have to deal most frequently with the decontamination of clothing and footwear. Such decontamination can also be complete or partial. Partial decontamination, as a rule, is carried out on contaminated territory or immediately after leaving the contaminated zone for the purpose of decreasing the contamination of clothing or footwear as much as possible, before they are subjected to complete decontamination. Partial decontamination of clothing is carried out using the simplest methods: by shaking out, sweeping down, brushing, etc. Shoes are brushed with brooms or wiped with damp rags.

The complete decontamination of clothing and shoes is carried out on uncontaminated territory, cleaning them more thoroughly using

the same methods employed in partial decontamination, and also utilizing other, more effective methods: pounding, vacuuming, laundering and washing in abundant water.

The best results are achieved with detergents and soap. Complete decontamination must be carried out in the following order. First the protective clothing must be taken off and processed and after that the shoes. If possible the shoes should be removed before decontamination. All this must be done while wearing protective masks and gloves. Masks and gloves should be removed only after decontamination has been completed. In conclusion the person himself must be decontaminated.

Under conditions created by radioactive contamination the population will frequently have to travel over contaminated territory and take part in various operations. Under all circumstances special warning signs, installed by the civil defense reconnaissance units will help the people to get their bearings on contarinated territory (See Fig. 11). These signs will designate the boundaries of contaminated zones with various radiation levels, they will mark lanes through contaminated territory, and the direction of the exit to uncontaminated territory.



a b

Fig. 11. Warning signs (a), and an inscription on a building designating contamination with radioactive substances (b).

Legend: 1 -- Contaminated, radioactive substances, 5 roentgens/hour 7 PM November 5; 2 -- Contaminated, 30 roentgens/hour 10 AM 23 October; 3 -- Contaminated, 15 roentgens/hour, 3 PM 3 July.

Using the signs it is possible to approximately evaluate the danger of remaining on contaminated terrain, for which purpose the

amount of radiation and time of its measurement, indicated on the sign should be considered. (In cases when a certain amount of time has elapsed since initial contamination, the level of radiation should be calculated using table 6 or the formula on page 17). In accordance with these data it is possible to determine the approximate dose that will be absorbed by a person, or the amount of time it is possible to remain on contaminated territory.

The radiation dose, level of radiation and time of irradiation are linked by the following simple relationship

$$D = Pt,$$

where D is the radiation dose; P -- is the radiation level, roentgens/hour; and t is the time (duration) of irradiation, hours.

When the radiation level and duration of irradiation (presence on contaminated territory) are known, the radiation dose is determined by multiplying these values by each other. If it is known, for instance, that the radiation level is 15 roentgens/hour and a person spent two hours on contaminated terrain, the dose he will have absorbed is equal to 30 roentgens ($D = 15 \cdot 2 = 30$).

The amount of time it is possible to spend on contaminated territory is determined in the reverse order -- by dividing the dose by the level of radiation. For example, if it is known that the radiation level is 10 roentgens per hour, while the dose which should not be exceeded is 20 roentgens, the time that it will be possible to spend on contaminated territory will be equal to two hours ($T = 20 : 10 = 2$ hours).

In solving these problems, however, it is necessary to take into consideration that the cited formula is very rough. It does not take into account the constant drop in the radiation level with time. In reality radiation doses will always be smaller, while the time that it is possible to spend on contaminated territory will be greater than that calculated according to the formula. Therefore the formula may be used only for approximate calculations and for small segments of time (not over several hours). When calculating doses for long periods of time this formula will lead to substantial errors.

In all cases when either presence or movement across contaminated territory is involved the necessary precautionary measures and rules of conduct must always be observed. For instance, the protective clothing may not be removed, the vehicles may not be dismounted during possible stops, no food may be consumed, smoking is prohibited, etc. When working on contaminated territory it is necessary to be cautious. One should try to avoid raising any dust, and contaminated objects must not be picked up or touched without need. It is also necessary to avoid contamination of the protective devices and, what is particularly important, the radiation dose must be monitored.

The protection of agricultural animals and food is closely associated with the protection of people. This is explained by the fact that contaminated animals, food and water may contaminate the people. Therefore measures to protect them against radioactive contamination are mandatory. Animals must also be protected because irradiation may make them ill or kill them. The consumption of contaminated feed and water by the animals must be limited. This must be done because part of the radioactive substances on the food and in the water consumed by the animals remain in their organism and, if too many

radioactive substances accumulate the meat may become unsuitable for human consumption.

Radioactive substances penetrating inside the organism of dairy cattle eventually become mixed with the milk.

In order to shelter the animals it is most feasible to utilize the conventional livestock barns. In order to increase their protective properties it is possible to block the windows with sand bags (crates). If there is time a board or cattle fence is erected several tens of centimeters from the walls with the intervening space filled with earth, in order to increase the protective properties of the walls.

Doors must be closed and ventilation ducts sealed in the cattle barns.

The herding of animals to the barns should be done ahead of time after the threat of contamination occurs.

It is necessary to prepare a stock of feed and water in the barns sufficient for several days. Before the contamination occurs (upon warning of radioactive contamination). A day's supply of feed and water should be left directly in the animal's troughs. This will make it unnecessary for the people to leave the shelters to feed the animals during the first and most dangerous 24 hours after contamination occurs.

The herding of cattle back to the pastures may be carried out only after the contamination of the vegetation has dropped to safe levels. It may take days or weeks for this to happen.

The task involving the protection of animals on distant pastures is more difficult to resolve for there are no barns there. It is quite difficult to shelter animals on such a pasture. Some protection is offered the animals by the leeward slopes of hills, gorges, forests, and ravines. In those areas the degree of vegetation and soil contamination as a rule, is lower than on open terrain.

Livestock casualties may be decreased if they are kept from consuming a large amount of contaminated grass. For this purpose the animals should be kept in barren areas for the first three days. At the first opportunity animals must be moved in an organized manner from contaminated to uncontaminated territory.

In order to prevent the food from becoming contaminated it must be packaged and sheltered. A small amount of food, for example, individual supplies, may be stored in wooden boxes or metal containers with tightly fitting lids. In order to keep the containers from becoming contaminated they should be wrapped in paper or a piece of fabric. Then, before removing the food the paper may be carefully removed and disposed of. This measure will considerably decrease the possibility of radioactive dust penetrating inside the containers as they are opened.

Large stocks of food are tightly packaged and stored in hermetically sealed storerooms. Fodder is also stored in buildings. If fodder is stored outdoors it must be carefully covered with a tarpaulin, hay, etc.

It is possible that the food or the fodder will become radioactively contaminated. In such a case they must be decontaminated prior to use. Solid food (meat, vegetables, fruit, etc.) may be

decontaminated by washing with water. In order to decontaminate solid as well as free-flowing food products it is possible to cut off (remove) the upper layer of the food product. After decontamination the products must be checked for radioactivity. Decontamination, as a rule, is feasible only for large stocks of food.

In order to prevent contamination of water with radioactive substances it must be stored in closed containers: bottles, teakettles, canisters, and the like. Larger stocks may be stored in barrels, tanks and other containers. In rural areas attention must be devoted to the protection of water in wells. To accomplish this the well cribwork should be covered with lids, and a shack be built over these wells. A clay cushion is poured around the well which prevents the seeping of contaminated water into the well.

It is quite difficult to decontaminate water since the radioactive substances mix with it. This may be done with the greatest success by filtration at the water pumping stations. The settling method or the filtering of water through home made coal or earth filters is recommended. After decontamination the water must be checked for the presence of radioactive substances.

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